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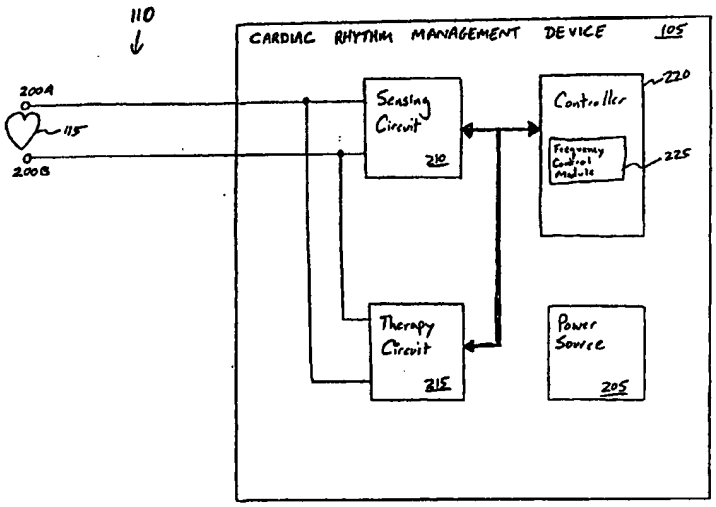

(57) Abstract

A cardiac rhythm management system includes a time-dependent frequency response for sensed heart signals. A change in the frequency response of a sensing circuit is triggered by sensed or evoked event to make it less sensitive to the detection of a subsequent event for a periof of time. For example, a passband bandwidth is reduced, then increased during the time period trigerred by the event. For even more event-trigerred selectivity, a gain is reduced, then increased during the time period trigerred by the event. This provides better discrimination between particular events included in a heart signal so that appropriate therapy can be delivered to the patient based on such events.

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CARDIAC RHYTHM MANAGEMENT SYSTEM WITH TIME-DEPENDENT FREQUENCY RESPONSE

Technical Field

This invention relates generally to cardiac rhythm management systems and particularly, but not by way of limitation, to a cardiac rhythm management system with a time-dependent frequency response for sensed heart signals.

Background

When functioning properly, the human heart maintains its own intrinsic rhythm, and is capable of pumping adequate blood throughout the body's circulatory system. However, some people have irregular cardiac rhythms, referred to as cardiac arrhythmias. Such arrhythmias result in diminished blood circulation. One mode of treating cardiac arrhythmias uses drug therapy. Drugs are often effective at restoring normal heart rhythms. However, drug therapy is not always effective for treating arrhythmias of certain patients. For such patients, an alternative mode of treatment is needed. One such alternative mode of treatment includes the use of a cardiac rhythm management system. Such systems are often implanted in the patient and deliver therapy to the heart.

Cardiac rhythm management systems include, among other things, pacemakers, also referred to as pacers. Pacers deliver timed sequences of low energy electrical stimuli, called pace pulses, to the heart, such as via a transvenous leadwire or catheter (referred to as a "lead") having one or more electrodes disposed in or about the heart. Heart contractions are initiated in response to such pace pulses (this is referred to as "capturing" the heart). By properly timing the delivery of pace pulses, the heart can be induced to contract in proper rhythm, greatly improving its efficiency as a pump. Pacers are often used to treat patients with bradyarrhythmias, that is, hearts that beat too slowly, or irregularly.

Cardiac rhythm management systems also include cardioverters or defibrillators that are capable of delivering higher energy electrical stimuli to the heart. Defibrillators are often used to treat patients with tachyarrhythmias, that is, hearts that beat too quickly. Such too-fast heart rhythms also cause

diminished blood circulation because the heart isn't allowed sufficient time to fill with blood before contracting to expel the blood. Such pumping by the heart is inefficient. A defibrillator is capable of delivering an high energy electrical stimulus that is sometimes referred to as a defibrillation countershock. The countershock interrupts the tachyarrhythmia, allowing the heart to reestablish a normal rhythm for the efficient pumping of blood. In addition to pacers, cardiac rhythm management systems also include, among other things, pacer/defibrillators that combine the functions of pacers and defibrillators, drug delivery devices, and any other systems or devices for diagnosing or treating cardiac arrhythmias.

One problem faced by cardiac rhythm management devices is the sensing of intrinsic heart signals. These electrical signals, which are commonly viewed on an electrocardiograph (ECG) display monitor, are produced by the body itself, and include depolarizations that result in heart contractions. For example, a sinoatrial node provides depolarization impulses, referred to as P-waves, that are normally conducted through atrial tissue, resulting a contraction of the atrial chamber of the heart. Such conducted atrial impulses normally reach the atrioventricular node, which then normally provides a resulting ventricular depolarization impulse, referred to as a QRS complex, that is conducted through the ventricular tissue, resulting in a contraction of the ventricular chamber of the heart. The intrinsic heart signals also include repolarizations, such as a T-wave that is generated as the ventricle relaxes and fills with blood before its next contraction. Thus, heart signals include various "events," including depolarizations (e.g., P-waves and QRS complexes), and also including repolarizations (e.g., T-waves).

It is important for a cardiac rhythm management device to be capable of distinguishing between various events sensed on such intrinsic heart signals, in order to ensure that appropriate therapy is delivered to the patient based on the sensed intrinsic heart signal. However, certain events, such as depolarizations and repolarizations, include similar frequency contents, making discrimination between these events difficult. There is a need for improved techniques of sensing intrinsic heart signals.

Summary

This document describes, among other things, a cardiac rhythm management system with a time-dependent frequency response for sensed heart signals. A change in the frequency response is triggered by a sensed or evoked event to make it less sensitive to the detection of a subsequent event for a period of time. This provides better discrimination between particular events included in a heart signal so that appropriate therapy can be delivered to the patient based such events.

In one embodiment, the cardiac rhythm management system includes a sensing circuit for sensing a heart signal, the sensing circuit having a frequency response that is time-dependent during a first time period initiated by one of an evoked or an intrinsic event of the heart signal.

In another embodiment, the cardiac rhythm management system, includes an electronics unit. The electronics unit includes a therapy circuit, a sensing circuit for sensing a heart signal of a heart, and a bandpass filter, included in the sensing circuit. The bandpass filter includes a frequency response that is time-dependent during a first time period initiated by one of an evoked or an intrinsic event of the heart signal. A leadwire is coupled to the electronics unit. A programmer, remote from and communicatively coupled to the electronics unit, includes a parameter controlling one of: (a) the frequency response of the bandpass filter, and (b) the duration of the first time period.

In another embodiment, the cardiac rhythm management system includes the following method. A heart signal that includes an intrinsic event is received from a heart. The heart signal is filtered to attenuate frequencies outside a frequency range having a first frequency range value. The event is detected. The frequency range is adjusted from the first frequency range value to a second frequency range value in response to the detection of the event.

In another embodiment, the cardiac rhythm management system includes the following method. A heart signal that includes an intrinsic event is received from a heart. A stimulation is provided to the heart for obtaining an evoked event. The heart signal is filtered to attenuate frequencies outside a first frequency range value. The intrinsic event is detected. The frequency range is narrowed from the first frequency range value to a second frequency range value

in response to (a) the detection of the intrinsic event, and (b) the providing the stimulation. The frequency range is widened from the second frequency range value, such that the frequency range approaches the first frequency range value after a first time period from (a) the detection of the intrinsic event and (b) the providing the stimulation. Other aspects of the invention will be apparent on reading the following detailed description of the invention and viewing the drawings that form a part thereof.

Brief Description of the Drawings

In the drawings, like numerals describe substantially similar components throughout the several views. Like numerals having different letter suffixes represent different instances of substantially similar components.

Figure 1 is a schematic drawing illustrating one embodiment of portions of a cardiac rhythm management system and an environment in which it is used.

Figure 2 is a schematic drawing illustrating one embodiment of portions of a cardiac rhythm management device and electrodes coupled to the heart, the device including a sensing circuit in which a frequency response is adjusted.

Figure 3 is a flow chart illustrating one embodiment of operating a cardiac rhythm management device.

Figure 4 is a flow chart illustrating another embodiment of operating a cardiac rhythm management device in which a sensed or evoked event (e.g., a ventricular sense or pace) triggers an increase in a highpass pole frequency for a period of time.

Figure 5 is a signal flow graph, corresponding to the flow chart of Figure 4, illustrating an intrinsic heart signal and frequency bandwidths of portions of the sensing circuit, in which a sensed event (e.g., a QRS complex) triggers an increase in a highpass pole frequency for a period of time.

Figure 6 is a signal flow graph, corresponding to the flow chart of Figure 4, illustrating an intrinsic heart signal and frequency bandwidths of portions of the sensing circuit, in which an event (e.g., a QRS complex) triggers an increase in a highpass pole frequency, followed by a gradual decrease in the highpass pole frequency during a period of time.

Figure **7** is a signal flow graph, corresponding to the flow chart of Figure **4**, in which an evoked event (e.g., a QRS complex) triggers an increase in the highpass pole frequency for a period of time.

Figure **8** is a flow chart illustrating another embodiment of operating a cardiac rhythm management device in which a sensed or evoked event (e.g., an atrial sense of pace) triggers a decrease in a lowpass pole frequency for a period of time.

Figure **9** is a signal flow graph, corresponding to the flow chart of Figure **8**, illustrating an intrinsic heart signal and frequency bandwidths of portions of the sensing circuit, in which a sensed event (e.g., a P-wave) triggers a decrease in a lowpass pole frequency for a period of time.

Figure **10** is a signal flow graph, corresponding to the flow chart of Figure **8**, illustrating an intrinsic heart signal and frequency bandwidths of portions of the sensing circuit in which an event (e.g., a P-wave) triggers a decrease in a lowpass pole frequency, followed by a gradual increase in the lowpass pole frequency during a period of time.

Figure **11** is a signal flow graph, corresponding to the flow chart of Figure **8**, in which an evoked event (e.g., a P-wave) triggers a decrease in the lowpass frequency.

Figure **12** is a flow chart illustrating another embodiment of operating a cardiac rhythm management device in which a sensed or evoked event (e.g., a QRS complex) triggers a narrowing of a passband bandwidth for a period of time.

Figure **13** is a signal flow graph, corresponding to the flow chart of Figure **12**, illustrating an intrinsic heart signal and frequency bandwidths of portions of the sensing circuit, in which a sensed event (e.g., a QRS complex) narrows a passband bandwidth for a period of time.

Figure **14** is a signal flow graph, corresponding to the flow chart of Figure **12**, illustrating an intrinsic heart signal and frequency bandwidths of portions of the sensing circuit in which an event (e.g., a QRS complex) triggers a narrowing of a passband, followed by a gradual increase in the passband during a period of time.

Figure **15** is a signal flow graph, corresponding to the flow chart of Figure **12**, in which an evoked event (e.g., a QRS complex) narrows a passband bandwidth for a period of time.

Figure **16** is a schematic diagram illustrating one embodiment of portions of a cardiac rhythm management device and electrodes coupled to the heart, the device including a sensing circuit in which a gain and a bandwidth of a frequency response is adjusted.

Figure **17** is a flow chart illustrating another embodiment of operating a cardiac rhythm management device in which a sensed or evoked event (e.g., a QRS complex) triggers a narrowing of a passband bandwidth and a decrease in gain for a period of time.

Figure **18** is a signal flow diagram, corresponding to the flow chart of Figure **17**, illustrating an intrinsic heart signal and frequency response of portions of the sensing circuit, in which a sensed event (e.g., a QRS complex) decreases a passband bandwidth and gain for a period of time.

Figure **19** is a signal flow graph, corresponding to the flow chart of Figure **17**, illustrating an intrinsic heart signal and frequency bandwidths of portions of the sensing circuit in which an event (e.g., a QRS complex) triggers a decrease in a passband bandwidth and gain, followed by a gradual increase in the passband bandwidth and gain during a period of time.

Figure **20** is a signal flow graph, corresponding to the flow chart of Figure **17**, in which an evoked event (e.g., a QRS complex) decreases a passband bandwidth and gain for a period of time.

Detailed Description

In the following detailed description, reference is made to the accompanying drawings which form a part hereof, and in which is shown by way of illustration specific embodiments in which the invention may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention, and it is to be understood that the embodiments may be combined, or that other embodiments may be utilized and that structural, logical and electrical changes may be made without departing from the spirit and scope of the present invention. The following detailed description is, therefore, not to be taken in a limiting sense, and the scope of the present invention is

defined by the appended claims and their equivalents. In the drawings, like numerals describe substantially similar components throughout the several views. Like numerals having different letter suffixes represent different instances of substantially similar components.

This document describes, among other things, a cardiac rhythm management system with a time-dependent frequency response for sensed heart signals. A change in the frequency response is triggered by a sensed or evoked event to make it less sensitive to the detection of a subsequent event for a period of time. This provides better discrimination between particular events included in a heart signal so that appropriate therapy can be delivered to the patient based such events.

Figure **1** is a schematic drawing illustrating, by way of example, but not by way of limitation, one embodiment of portions of a cardiac rhythm management system **100** and an environment in which it is used. In Figure **1**, system **100** includes an implantable cardiac rhythm management device **105**, also referred to as an electronics unit, which is coupled by an intravascular endocardial lead **110** to a heart **115** of patient **120**. System **100** also includes an external programmer **125** providing wireless communication with device **105** using a telemetry device **130**. Lead **110** includes a proximal end **135**, which is coupled to device **105**, and a distal end **140**, which is coupled to one or more portions of heart **115**.

Figure **2** is a schematic drawing illustrating, by way of example, but not by way of limitation, one embodiment of portions of cardiac rhythm management device **105**, and electrodes **200A-B** coupled to heart **115**. In this embodiment device **105** includes a power source **205**. A sensing circuit **210** senses intrinsic heart signals obtained at electrodes **200A-B** or otherwise. A therapy circuit **215** is coupled to electrodes **200A-B**, or to other electrodes coupled to heart **115**, for delivering pacing stimulations and/or defibrillation countershock therapy. A microprocessor or other controller **220** receives signals from, and provides control signals to, sensing circuit **210** and therapy circuit **215**.

Sensing circuit **210** includes continuous-time and/or discrete-time (e.g., switched capacitor) amplification and filter circuits, which provide an overall frequency response of sensing circuit **210**. In one embodiment, controller **220**

includes a frequency control module **225** for providing control signals for adjusting a frequency response of portions of sensing circuit **210**, as discussed below. The frequency response is adjusted in response to a detected event obtained from the intrinsic heart signal and/or an evoked event obtained by providing therapy (e.g., a pacing stimulation) from therapy circuit **215**.

Figure **3** is a flow chart illustrating generally, by way of example, but not by way of limitation, one embodiment of operating device **105**. At step **300**, if an intrinsic event on the heart signal is detected by sensing circuit **210**, or if therapy circuit **215** delivers therapy to evoke an event on the heart signal, then at step **305**, a frequency response of sensing circuit **210** is adjusted. At step **310**, after a first time period the frequency response of sensing circuit **210** is then restored, to its value prior to step **305**, until another detected or evoked event occurs at step **300**.

Example with Highpass Pole

Figure **4** is a flow chart illustrating generally, by way of example, but not by way of limitation, another embodiment of operating device **105**. Figure **5** is a signal flow graph, corresponding to the flow chart of Figure **4**, illustrating intrinsic heart signal **500** and frequency bandwidths of portions of sensing circuit **210**. At time t_0, before step **400**, sensing circuit **210** includes, among other things, a highpass frequency response that includes at least one highpass pole at or near a first frequency value, f_1.

At step **400** and time t_1, if an intrinsic ventricular event, such as QRS complex **505**, is sensed or ventricular therapy, such as a ventricular pacing stimulation, is delivered, then at step **405**, a highpass pole frequency increases from a first frequency value, f_1, to a higher second frequency value, f_2. As a result, sensing circuit **210** is subsequently more likely to reject lower frequency events such as T-wave **510**, which includes frequency components below f_2. Thus, the attenuation of T-wave **510** and other low frequency events is increased immediately after QRS complex **505** is detected. Stated differently, sensing circuit **210** is less sensitive to T-wave detection during a time period immediately following a QRS detection. Sensing circuit is therefore less likely to erroneously detect a particular T-wave **510** as a QRS complex.

At step **410** and time t_2, the highpass pole frequency of sensing circuit **210** decreases from f_2 back to f_1. As a result, after the first time period $t_2 - t_1$, sensing circuit **210** is again made more sensitive to QRS complexes, which include frequency components above f_1. In one embodiment, the highpass pole frequency is switched from f_1 to f_2 at time t_1, and switched back to f_1 at time t_2. In another embodiment, the highpass pole frequency is switched from f_1 to f_2 at time t_1, but the highpass pole frequency is gradually decreased from f_2 back toward f_1 during the first time period $t_2 - t_1$, such that the highpass pole frequency approaches f_1 at time t_2, as illustrated in Figure **6**. In this embodiment, the frequency response is time dependent during the first time period $t_2 - t_1$. In one embodiment, the first time period $t_2 - t_1$ is greater than or equal to 250 milliseconds, such as approximately between 250 milliseconds and 500 milliseconds or at approximately 500 milliseconds. Thus, the first time period, in this embodiment, is sufficiently long to allow the ventricle to repolarize (allow a T-wave) while the sensitivity of the sensing circuit **210** is still reduced. In one embodiment, programmer **125** communicates to device **105** a parameter controlling one of: (a) the frequency response of the sensing circuit, and (b) the duration of the first time period.

Figure **7** is a signal flow graph, similar to Figure **5**, illustrating the case of step **400** in which therapy, such as a ventricular pacing stimulation, is delivered at time t_1, thereby evoking QRS complex **505**, and initiating the adjustment in the frequency response of sensing circuit **210** by increasing the highpass pole from f_1 to f_2 for a first time period $t_2 - t_1$ to make the sensing circuit less sensitive to T-wave **510** during the first time period.

Example with Lowpass Pole

Figure **8** is a flow chart illustrating generally, by way of example, but not by way of limitation, another embodiment of operating device **105**. Figure **9** is a signal flow graph, corresponding to the flow chart of Figure **8**, illustrating intrinsic heart signal **900** and frequency bandwidths of portions of sensing circuit **210**. At time t_0, before step **800**, sensing circuit **210** includes, among other things, a lowpass frequency response that includes at least one lowpass pole at or near a first frequency value, f_1.

At step **800** and time t_1, if an intrisic atrial event, such as P-wave **905**, is sensed or atrial therapy, such as an atrial pacing stimulation, is delivered, then at step **805**, the lowpass pole frequency decreases from first frequency value, f_1, to a lower second frequency value, f_2. As a result, sensing circuit **210** is subsequently more likely to reject higher frequency events such as QRS complex **910**, which includes frequency components above f_2. Thus, the attenuation of QRS complex **910** and other high frequency events is increased immediately after P-wave **905** is detected. Stated differently, sensing circuit **210** is less sensitive to QRS complex detection during a time period immediately following a P-wave detection. Sensing circuit is therefore less likely to erroneously detect a particular QRS complex **910** as a P-wave.

At step **810** and time t_2, the lowpass pole frequency of sensing circuit **210** increases from f_2 to f_1. As a result, after the first time period $t_2 - t_1$, sensing circuit **210** is more sensitive to P-waves, which include frequency components below f_1. In one embodiment, the lowpass pole frequency is switched from f_1 to f_2 at time t_1, and switched back to f_1 at time t_2. In another embodiment, the lowpass pole frequency is switched from f_1 to f_2 at time t_1, but the lowpass pole frequency is gradually increased from f_2 back toward f_1 during the first time period $t_2 - t_1$, such that the lowpass pole frequency approaches f_1 at time t_2, as illustrated in Figure **10**. In this embodiment, the frequency response is time dependent during the time period $t_2 - t_1$.

Figure **11** is a signal flow graph, similar to Figure **9**, illustrating the case of step **800** in which therapy, such as an atrial pacing stimulation, is delivered at time t_1, thereby evoking P-wave **905**, and initiating the adjustment in the frequency response of sensing circuit **210** by decreasing the lowpass pole from f_1 to f_2 for a first time period $t_2 - t_1$ to make the sensing circuit less sensitive to QRS complex **910** during the first time period.

Example with Lowpass and Highpass Poles

Figure **12** is a flow chart illustrating generally, by way of example, but not by way of limitation, another embodiment of operating device **105**. Figure **13** is a signal flow graph of intrinsic heart signal **1300** and frequency bandwidths of portions of sensing circuit **210**, corresponding to Figure **12**. At time t_0, before step **800**, sensing circuit **210** includes, among other things, a bandpass frequency

response that includes at least one highpass pole at or near a first frequency value, f_1, and at least one lowpass pole at or near a third frequency value, f_3.

At step **800** and time t_1, if an intrisic sensed event, such as QRS complex **1305**, is sensed or therapy, such as a pacing stimulation, is delivered, then at step **1205**, the highpass pole frequency increases from first frequency value, f_1, to a higher second frequency value, f_2, and the lowpass pole frequency decreases from third frequency value f_3 to a lower fourth frequency value f_4. As a result, sensing circuit **210** is subsequently more likely to reject frequencies outside the frequency range f_4 - f_2, which includes frequencies of QRS complex **1305**. Thus, attenuation and rejection of T-wave **1310** is increased immediately after QRS complex **1305** is detected. Stated differently, sensing circuit **210** is less sensitive to T-wave detection during a time period immediately following a QRS complex detection. Sensing circuit **210** is therefore less likely to erroneously detect a particular T-wave **1310** as a QRS complex.

At step **1210** and time t_2, the highpass pole frequency of sensing circuit **210** decreases from f_2 back to f_1, and the lowpass pole frequency of sensing circuit **210** increases from f_4 back to f_3. As a result, after the first time period t_2 - t_1, such as during the time period t_3 - t_2, sensing circuit **210** is made again more sensitive to T-waves. In one embodiment, the lowpass and highpass pole frequency are switched at time t_1 and switched back at time t_2. In another embodiment, the lowpass and highpass pole frequencies are switched at time t_1, and then gradually returned toward their original values during the first time period t_2 - t_1, as illustrated in Figure **14**. In this embodiment, the frequency response is time dependent during the time period t_2 - t_1.

Figure **15** is a signal flow graph, similar to Figure **13**, illustrating the case of step **1200** in which therapy, such as a pacing stimulation, is delivered at time t_1, thereby evoking QRS complex **1305**, and initiating the adjustment in the frequency response of sensing circuit **210** to make the sensing circuit less sensitive to T-wave **1310** during the first time period t_2 - t_1.

Example with Frequency and Gain Adjustment

Figure **16** is a schematic diagram illustrating generally, by way of example, but not by way of limitation, another embodiment of device **105** in which controller **220** further includes a gain control module **1600**, which

provides control signals to a bandpass filter **1605** in sensing circuit **210** for controlling at least one passband gain contributing to the overall frequency response of sensing circuit **210**, in addition to the frequency control module **225** that controls at least one frequency bandwidth of bandpass filter **1605** in sensing circuit **210**.

Figure **17** is a flow chart illustrating generally, by way of example, but not by way of limitation, another embodiment of operating device **105** in which both the frequency bandwidth and gain are adjusted in response to a detected event obtained from the intrinsic heart signal and/or an evoked event obtained by providing therapy (e.g., a pacing stimulation) from therapy circuit **215**. Figure **18** is a signal flow graph, corresponding to the flow chart of Figure **17**, that illustrates intrinsic heart signal **1800** and frequency bandwidths of portions of sensing circuit **210**. At time t_0, before step **1700**, sensing circuit **210** includes, among other things, a bandpass frequency response that includes at least one highpass pole at or near a first frequency value, f_1, and at least one lowpass pole at or near a third frequency value, f_3, and a first passband gain of approximately G_1.

At step **1700** and time t_1, if an intrisic sensed event, such as QRS complex **1805**, is sensed or therapy, such as a pacing stimulation, is delivered, then at step **1705**, the highpass pole frequency increases from first frequency value, f_1, to a higher second frequency value, f_2, the lowpass pole frequency decreases from third frequency value f_3 to a lower fourth frequency value f_4, and the passband gain decreases from G_1 to a second passband gain of approximately G_2. As a result, sensing circuit **210** is subsequently less sensitive. Thus, attenuation and rejection of T-wave **1810**, having frequency components that are very close in frequency to frequency components of QRS complex **1805**, is increased immediately after QRS complex **1805** is detected. Stated differently, sensing circuit **210** is less sensitive to T-wave detection during a time period immediately following a QRS complex detection. Sensing circuit **210** is therefore less likely to erroneously detect a particular T-wave **1810** as a QRS complex.

At step **1810** and time t_2, the highpass pole frequency of sensing circuit **210** decreases from f_2 back to f_1, the lowpass pole frequency of sensing circuit

210 increases from f_4 back to f_3, and the passband gain increases from G_2 to G_1. As a result, after the first time period $t_2 - t_1$, such as during the time period $t_3 - t_2$, sensing circuit **210** is made again more sensitive to T-waves. In one embodiment, the lowpass and highpass pole frequencies and the passband gain are switched at time t_1 and switched back at time t_2. In another embodiment, the lowpass and highpass pole frequencies and passband gain are switched at time t_1, and then gradually returned toward their original values during the first time period $t_2 - t_1$, as illustrated in Figure **19**. In this embodiment, both the gain and the bandwidth of the frequency response are time dependent during the time period $t_2 - t_1$.

Figure **20** is a signal flow graph, similar to Figure **19**, illustrating the case of step **1800** in which therapy, such as a pacing stimulation, is delivered at time t_1, thereby evoking QRS complex **1805**, and initiating the adjustment in the gain and frequency response of sensing circuit **210** to make the sensing circuit less sensitive to T-wave **510** during the first time period $t_2 - t_1$. Although Figures **18** - **20** illustrate using the same time period for adjusting the gain and bandwidth, it is understood that different time periods can be used for adjusting the gain and bandwidth. For example, an event can trigger a first time period over which the frequency bandwidth is reduced, and also trigger a second time period, different from the first time period, over which the gain is reduced.

Conclusion

The above-described system provides, among other things, a cardiac rhythm management system with a time-dependent frequency response for sensed heart signals. A change in the frequency response is triggered by a sensed or evoked event to make it less sensitive to the detection of a subsequent event for a period of time. This provides better discrimination between particular events included in a heart signal so that appropriate therapy can be delivered to the patient based such events.

It is to be understood that the above description is intended to be illustrative, and not restrictive. Although particular embodiments have been described, combinations of such embodiments are understood to be included within the scope of the invention. Many other embodiments will be apparent to those of skill in the art upon reviewing the above description. The scope of the

invention should, therefore, be determined with reference to the appended claims, along with the full scope of equivalents to which such claims are entitled.

WHAT IS CLAIMED IS:

1. A cardiac rhythm management system, including a sensing circuit for sensing a heart signal, the sensing circuit having a frequency response that is time-dependent during a first time period initiated by one of an evoked or an intrinsic event of the heart signal.

2. The system of claim 1, in which the frequency response includes a bandwidth that is time-dependent for the first time period, and the first time period is initiated by both evoked and intrinsic events of the heart signal.

3. The system of claim 2, in which the bandwidth is time-dependent for the first time period, and the first time period is initiated by both evoked and intrinsic QRS complexes of the heart signal.

4. The system of claim 3, in which the bandwidth decreases to a second bandwidth value, from a first bandwidth value, upon occurrence of the event.

5. The system of claim 4, in which the bandwidth increases from the second bandwidth value toward the first bandwidth value during the first time period.

6. The system of claim 5, in which the bandwidth includes a passband.

7. The system of claim 6, in which an attenuation of a T-wave of the heart signal during the first time period is greater than or equal to the attenuation of the T-wave immediately after expiration of the first time period.

8. The system of claim 7, in which the first time period is greater than or equal to 250 milliseconds.

9. The system of claim 8, in which the first time period is approximately between 250 milliseconds and 500 milliseconds.

10. The system of claim 8, in which the first time period is approximately 500 milliseconds.

11. The system of claim 10, in which the sensing circuit includes an automatic gain control (AGC) circuit.

12. The system of claim 1, in which a highpass pole frequency is time-dependent for the first time period, and the first time period is initiated by both evoked and intrinsic events of the heart signal.

13. The system of claim 12, in which the first time period is initiated by both evoked and intrinsic QRS complexes, and the highpass pole frequency increases to a second frequency value, from a steady-state first frequency value, in response to detection of a QRS complex.

14. The system of claim 13, in which the highpass pole frequency decreases from the second frequency value toward the first frequency value during the first time period.

15. The system of claim 1, in which a lowpass pole frequency is time-dependent for the first time period, and the first time period is initiated by both evoked and intrinsic events of the heart signal.

16. The system of claim 15, in which the first time period is initiated by both evoked and intrinsic QRS complexes, and the lowpass pole frequency decreases to a second frequency value, from a first frequency value during the first time period.

17. The system of claim 16, in which the first time period is initiated by both evoked and intrinsic QRS complexes, and the lowpass pole frequency increases from the second frequency value toward the first frequency value during the first time period.

18. The system of claim **1**, in which the sensing circuit includes a gain that is time-dependent during a second time period initiated by one of the evoked or the intrinsic event of the heart signal.

19. The system of claim **18**, in which the second time period is initiated by both the evoked and the intrinsic event of the heart signal.

20. The system of claim **19**, in which the gain decreases to a second gain value, from a first gain value, during the second time period.

21. The system of claim **20**, in which the gain increases, from the second gain value toward the first gain value during the second time period.

22. A cardiac rhythm management system, including:

an electronics unit including:

a therapy circuit;

a sensing circuit for sensing a heart signal of a heart; and

a bandpass filter, included in the sensing circuit, the filter having a frequency response that is time-dependent during a first time period initiated by one of an evoked or an intrinsic event of the heart signal; and

a leadwire, coupled to the electronics unit; and

a programmer, remote from and communicatively coupled to the electronics unit, the programmer including a parameter controlling one of: (a) the frequency response of the bandpass filter, and (b) the duration of the first time period.

23. The system of claim **22**, in which the sensing circuit further includes a gain that decreases from a first gain value to a second gain value during a second time period initiated by one of the evoked or the intrinsic event of the heart signal.

24. A method including:

receiving, from a heart, a heart signal that includes an intrinsic event;

filtering the heart signal to attenuate frequencies outside a frequency range having a first frequency range value;

detecting the event; and

adjusting the frequency range from the first frequency range value to a second frequency range value in response to the detection of the event.

25. The method of claim **24**, further including adjusting the frequency range from the second frequency range value toward the first frequency range value during a first time period from the event.

26. The method of claim **25**, further including;

providing a stimulation to the heart; and

adjusting the frequency range from the first frequency range value to the second frequency range value in response to the providing the stimulation.

27. The method of claim **26**, further including adjusting the frequency range from the second frequency range value toward the first frequency range value during a first time period from the stimulation.

28. The method of claim **24**, further including:

amplifying the heart signal by a gain; and

reducing the gain from a first gain value to a second gain value in response to the detection of the event.

29. A method including:

receiving, from a heart, a heart signal that includes an intrinsic event;

providing, to the heart, a stimulation for obtaining an evoked event;

filtering the heart signal to attenuate frequencies outside a frequency range having a first frequency range value;

detecting the intrinsic event;

narrowing the frequency range from the first frequency range value to a second frequency range value in response to (a) the detection of the intrinsic event, and (b) the providing the stimulation; and

widening the frequency range from the second frequency range value such that the frequency range approaches the first frequency range value after a first time period from (a) the detection of the intrinsic event and (b) the providing the stimulation.

30. The method of claim **29**, in which:

detecting the intrinsic event includes detecting a QRS complex; and

filtering the heart signal includes filtering the heart signal to attenuate frequencies outside the frequency range having the first frequency range value that includes frequency components of the QRS complex.

31. The method of claim **30**, in which narrowing the frequency range includes attenuating a T-wave.

32. The method of claim **31**, in which filtering the heart signal includes bandpass filtering the heart signal.

33. The method of claim **29**, further including:

amplifying the heart signal by a gain; and

reducing the gain from a first gain value to a second gain value in response to (a) the detection of the intrinsic event and (b) the providing the stimulation.

34. The method of claim **33**, further including increasing the gain from the second gain value toward the first gain value during a second time period following one of (a) the detection of the intrinsic event and (b) the providing the stimulation.

35. The method of claim **34**, in which the first and second time periods are approximately equal.

36. The method of claim **34**, in which the first and second time periods are different.

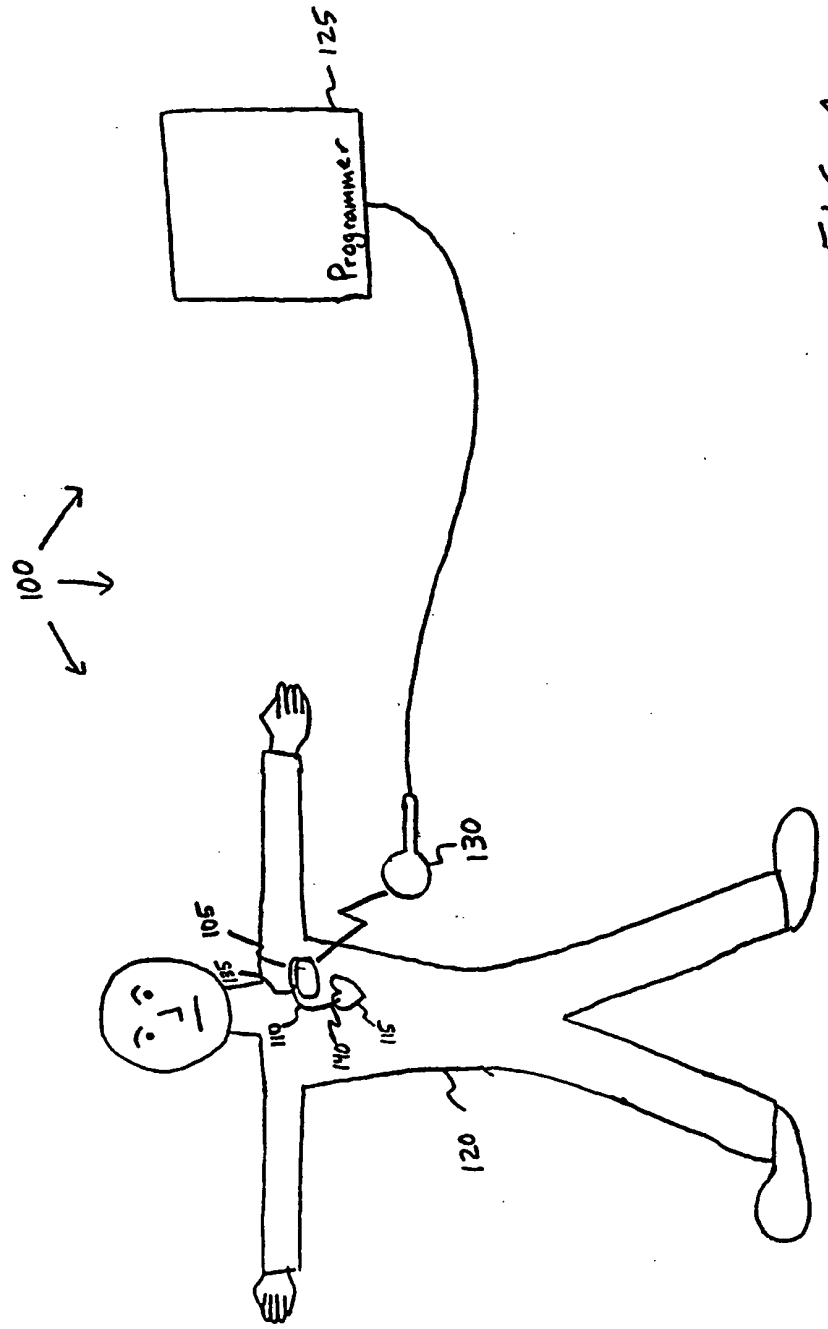

FIG. 1

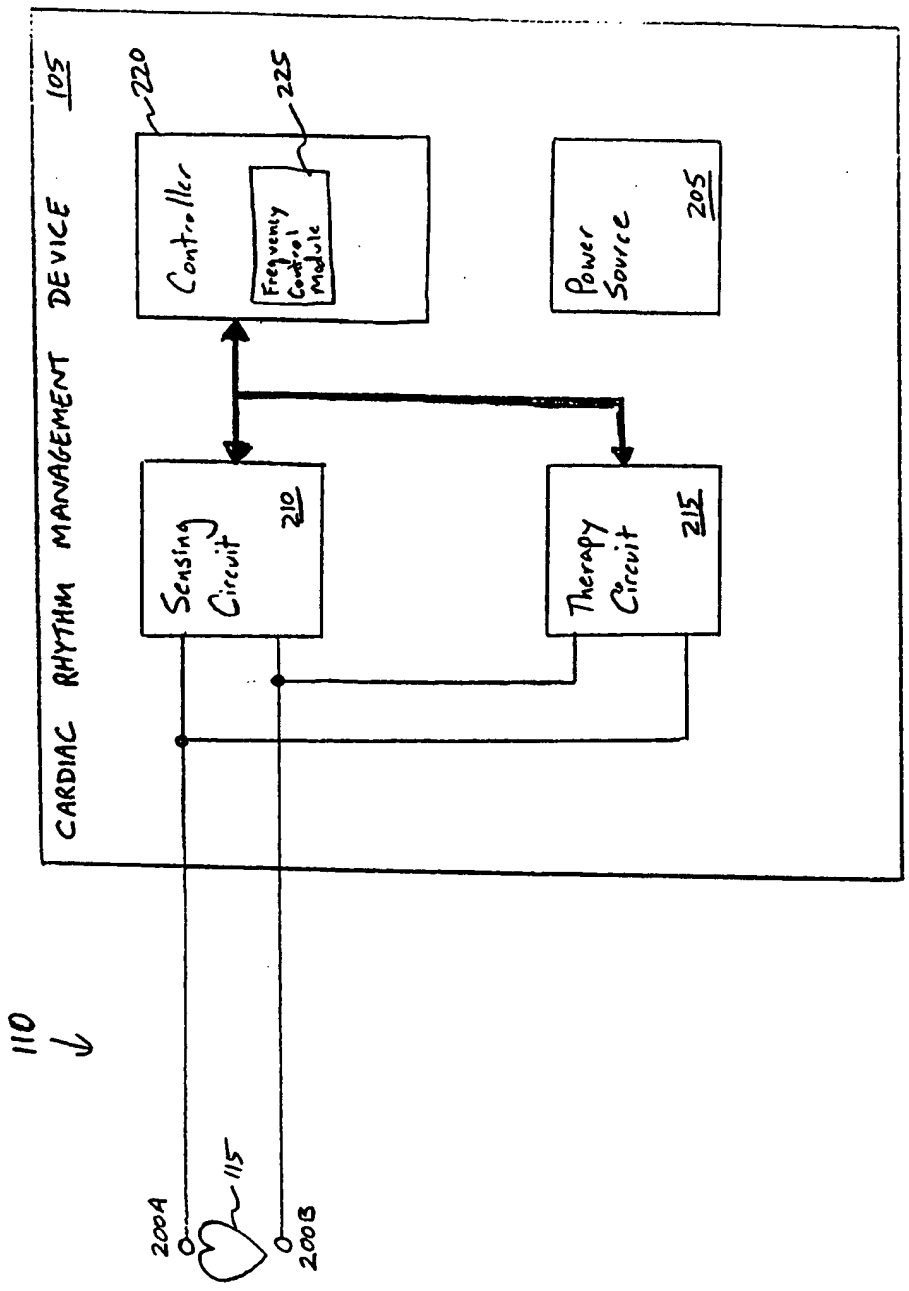
CARDIAC RHYTHM MANAGEMENT DEVICE
105
220
Controller
225
Frequency Control Module
Power Source
205
Sensing Circuit
210
Therapy Circuit
215
110
115
200A
200B

FIG. 2

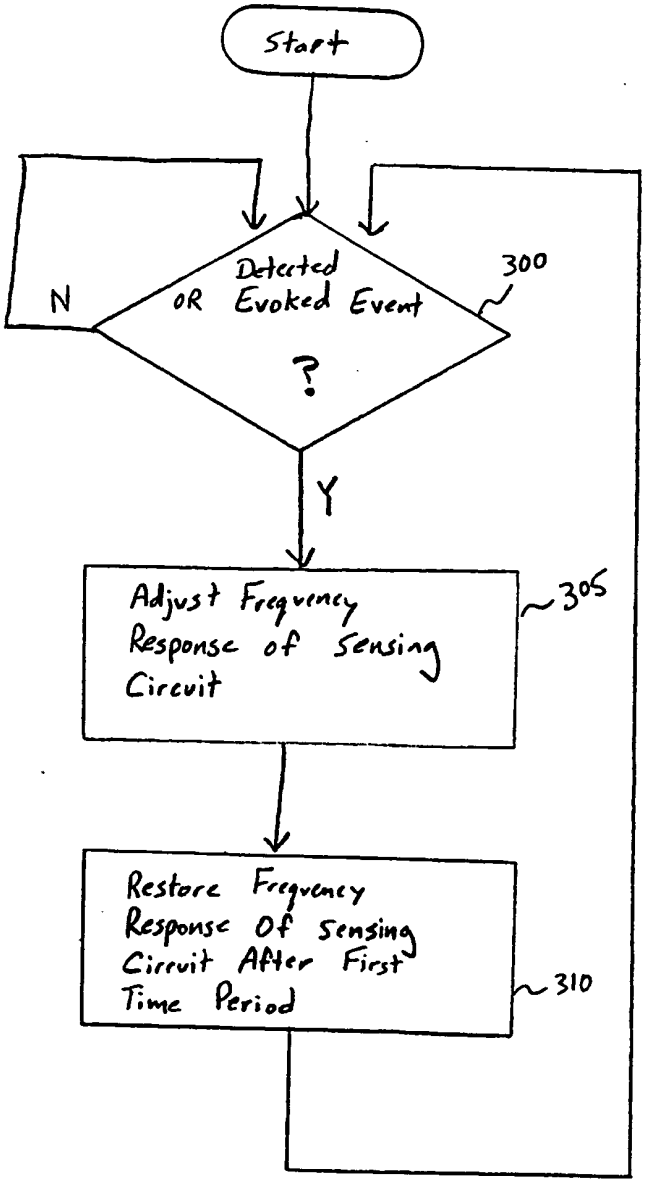
Start
Detected OR Evoked Event ?
300
N
Y
Adjust Frequency Response of Sensing Circuit
305
Restore Frequency Response Of Sensing Circuit After First Time Period
310

FIG. 3

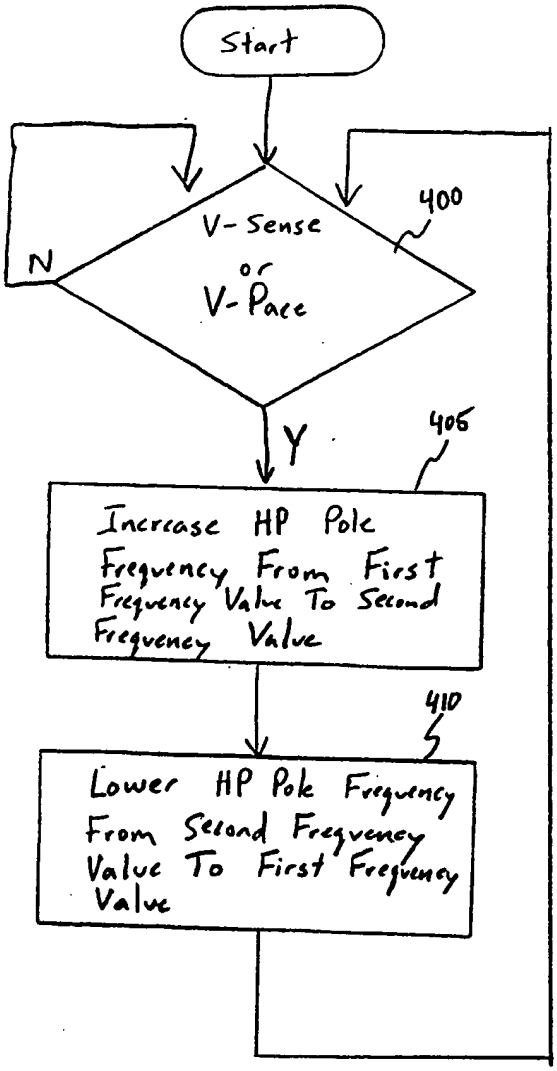
Start
V-Sense
or
V-Pace
400
N
Y
406
Increase HP Pole Frequency From First Frequency Value To Second Frequency Value
410
Lower HP Pole Frequency From Second Frequency Value To First Frequency Value

FIG. 4

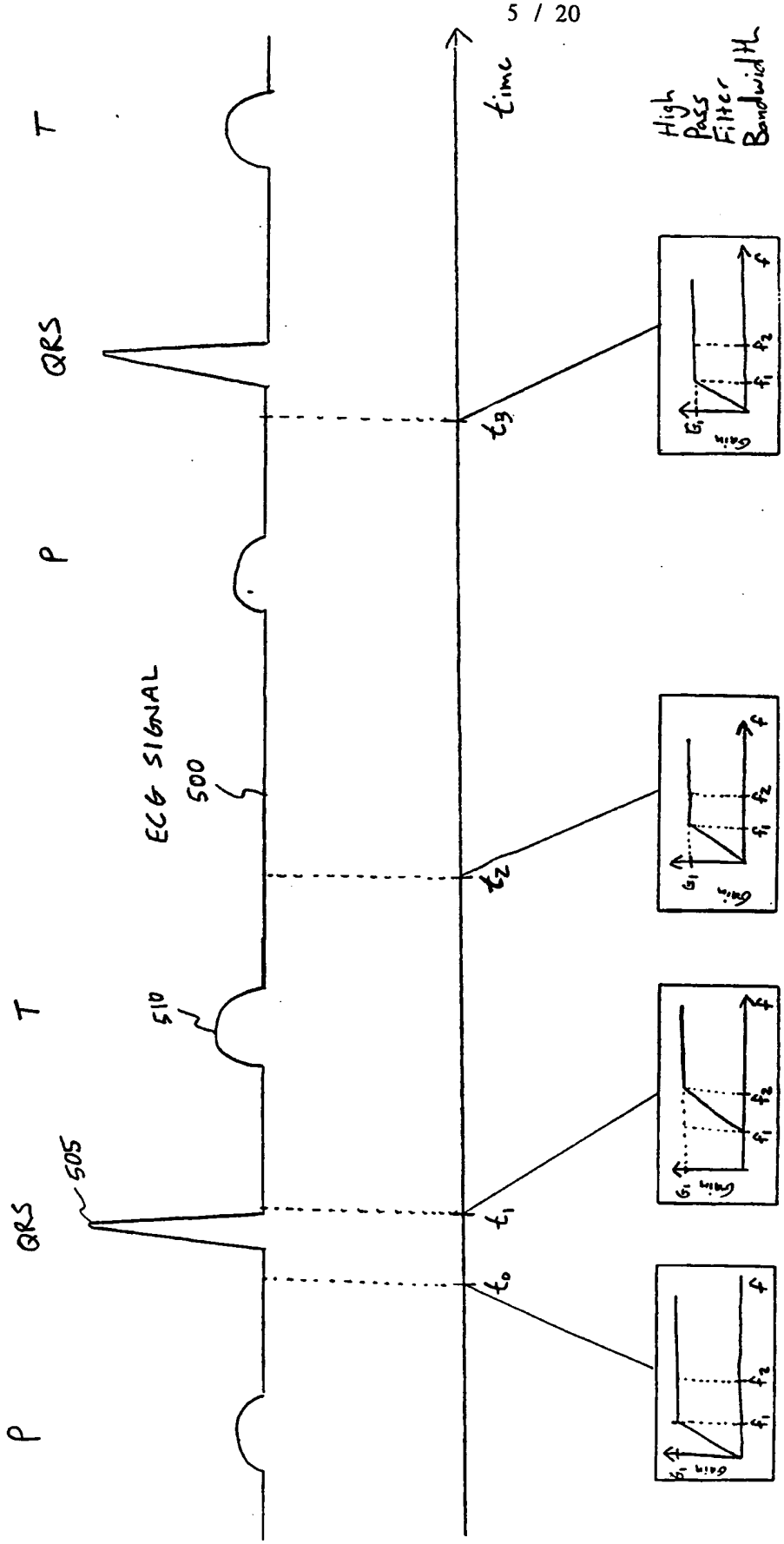
T
QRS
P
ECG SIGNAL
500
T
510
QRS
505
P
time
High Pass Filter Bandwidth
t_3
t_2
t_1
t_0
f_1
f_2
G_1
Gain

FIG. 5

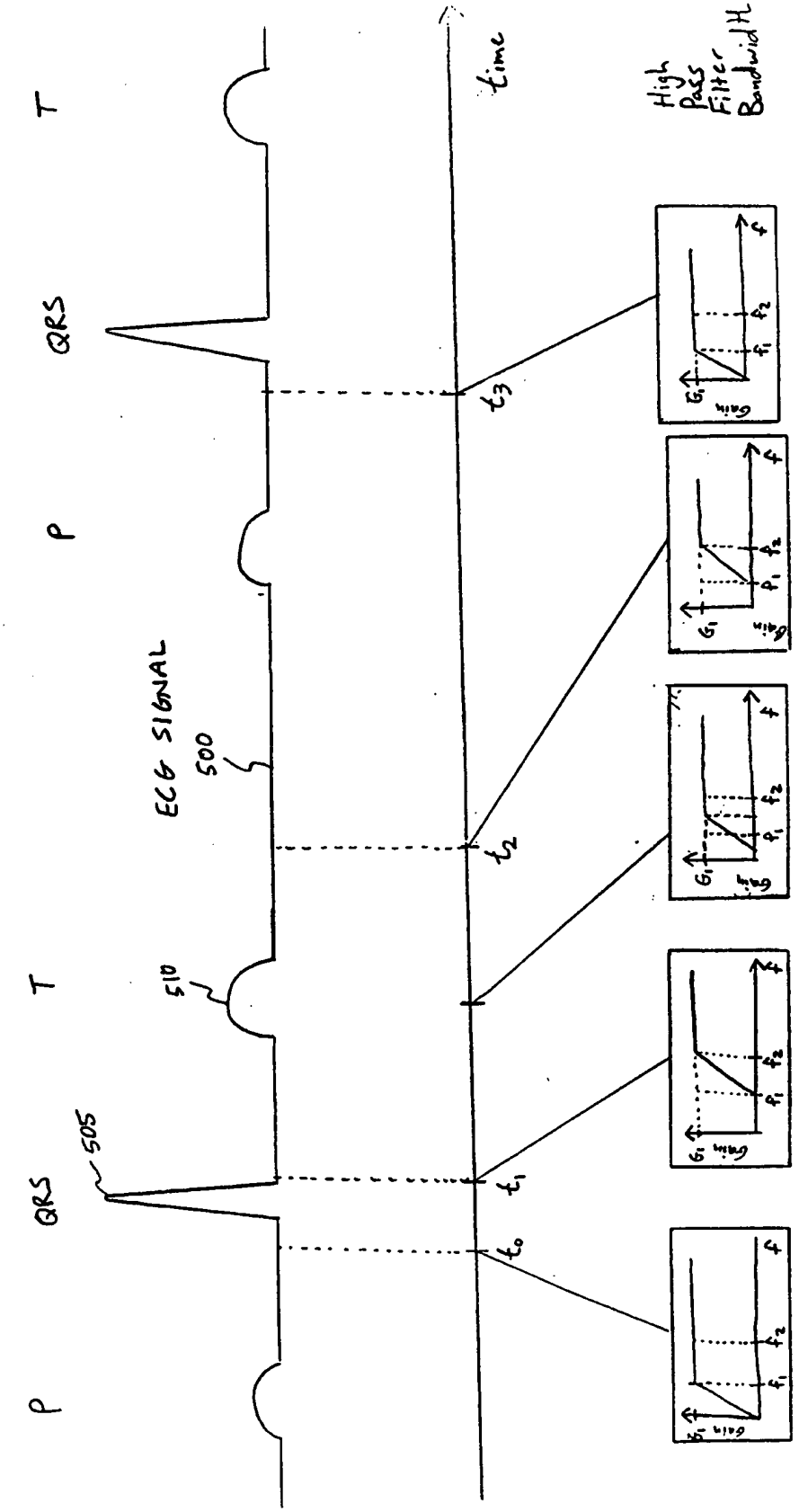
T
QRS
P
ECG SIGNAL
500
T
510
QRS
505
P
time
t_3
t_2
t_1
t_0
High Pass Filter Bandwidth
f
f_2
f_1
Gain
G_1

FIG. 6

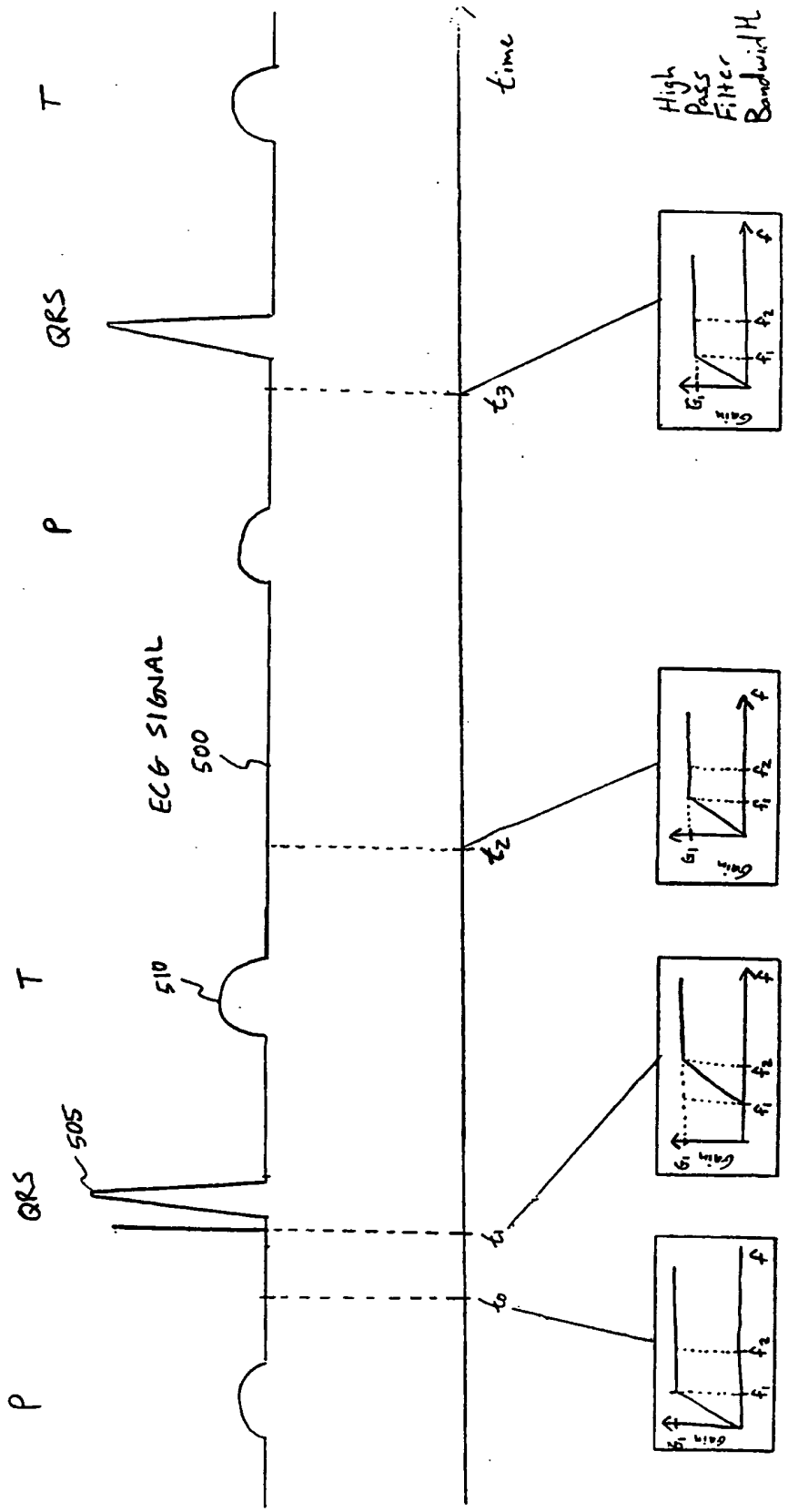
T
QRS
P
ECG SIGNAL
500
T
510
QRS
505
P
Time
High Pass Filter Bandwidth
Gain
f1
f2
f3
f4
G1
t0
t1
t2
t3

FIG. 7

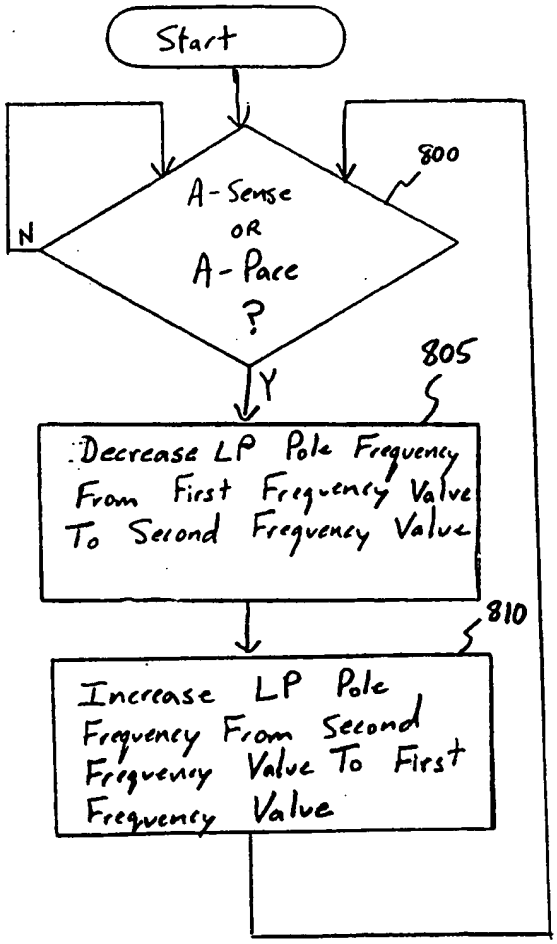
Start
A-Sense OR A-Pace ?
800
N
Y
805
Decrease LP Pole Frequency From First Frequency Valve To Second Frequency Valve
810
Increase LP Pole Frequency From Second Frequency Valve To First Frequency Valve

FIG. 8

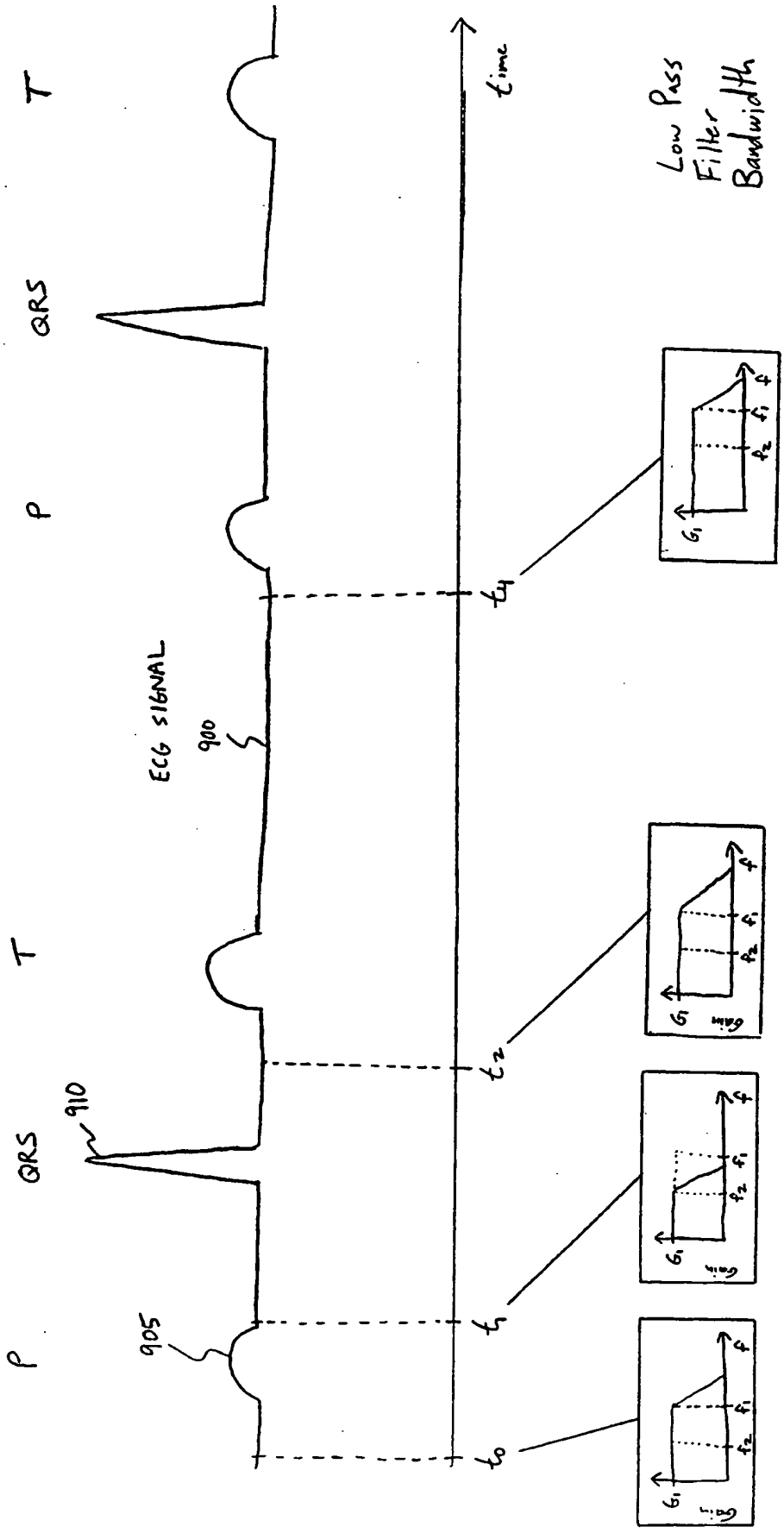
T
QRS
P
T
QRS
P
ECG SIGNAL
900
910
905
time
Low Pass Filter Bandwidth
t_4
t_2
t_1
t_0
f_1
f_2
G_1
Gain

FIG. 9

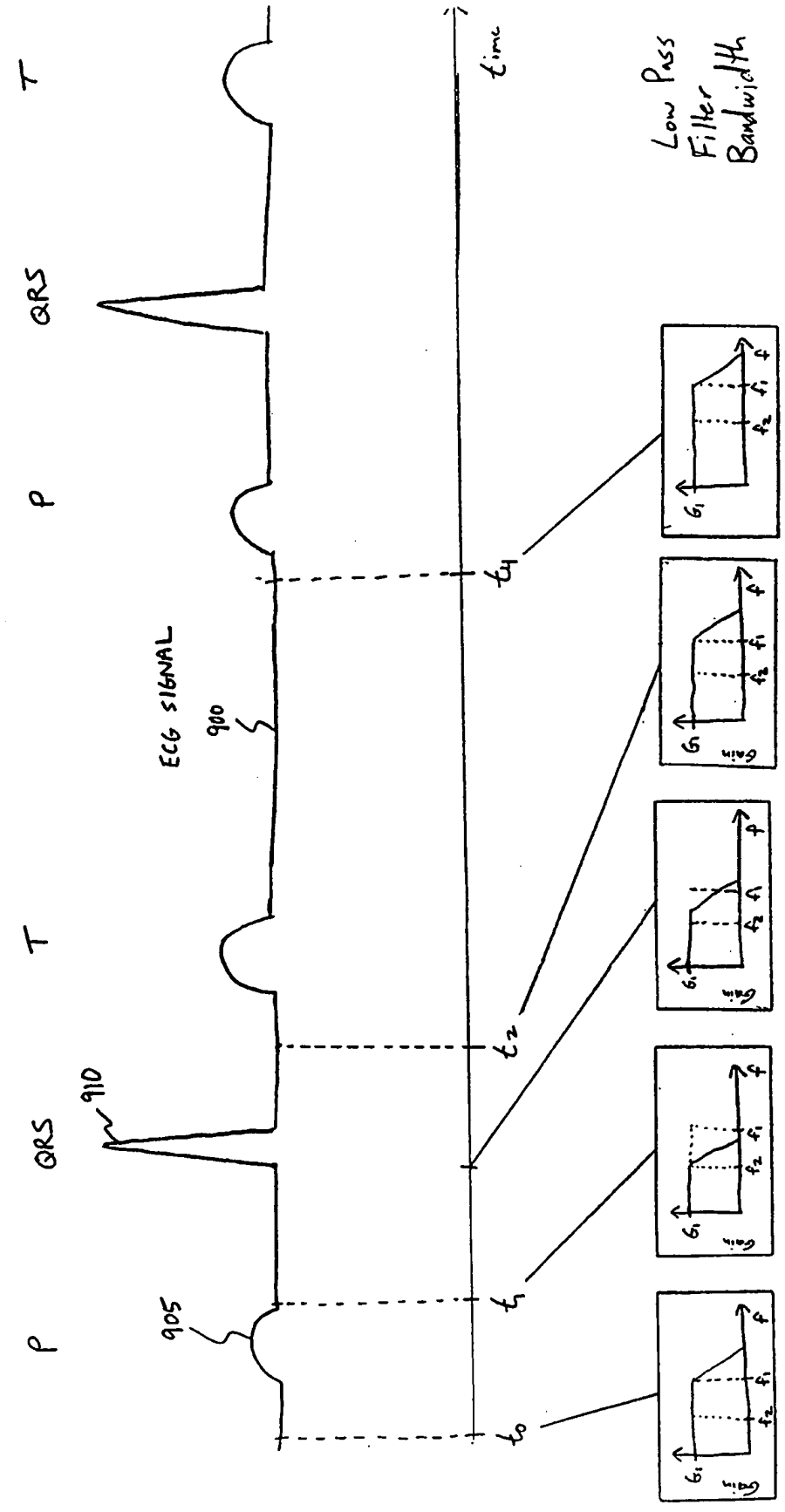
T
QRS
P
ECG SIGNAL
900
T
QRS
910
P
905
time
Low Pass Filter Bandwidth
t_4
t_2
t_1
t_0
f
f_1
f_2
G_1
Gain

FIG. 10

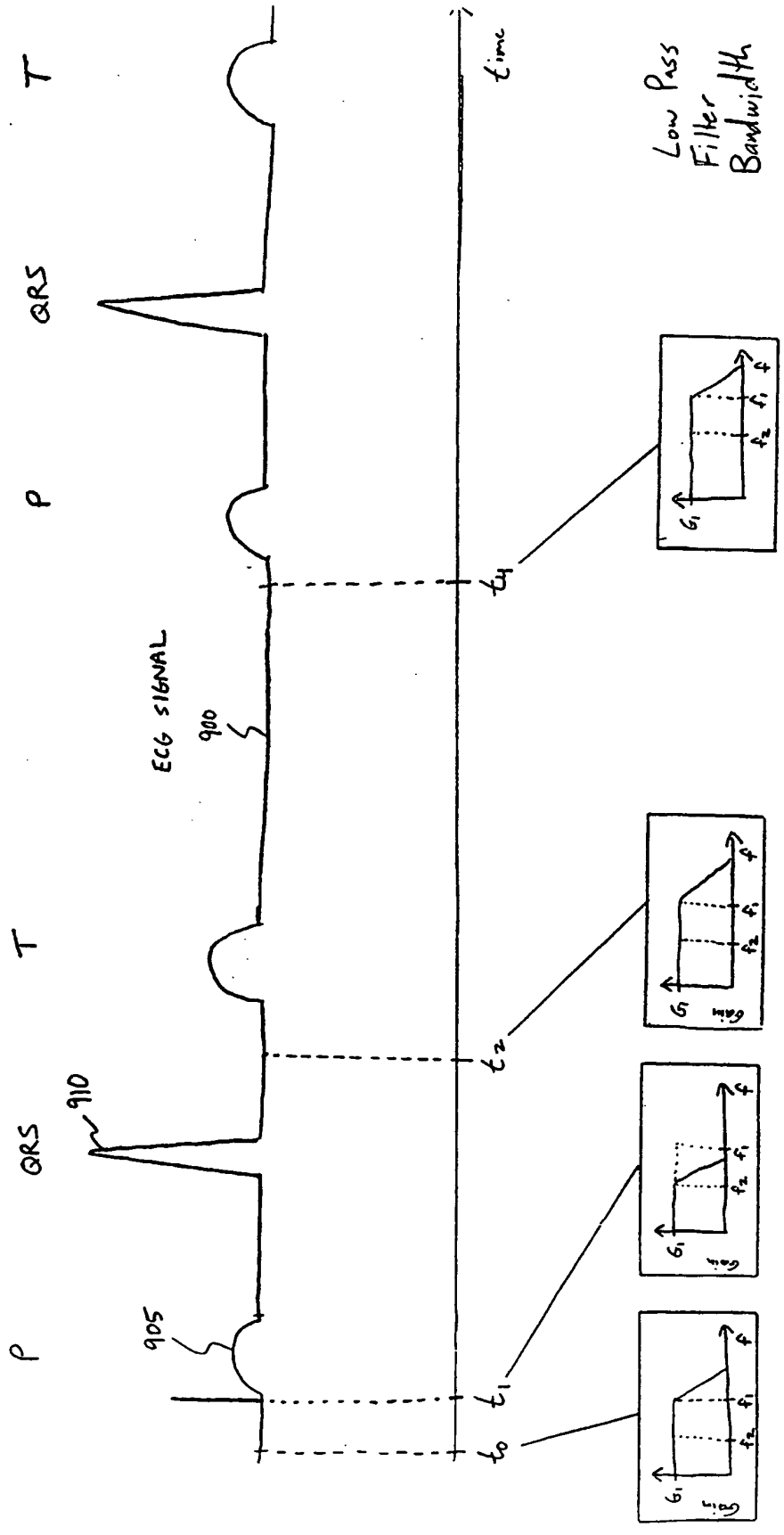
T
QRS
P
T
QRS
P
ECG SIGNAL
900
905
910
time
Low Pass Filter Bandwidth
t_4
t_2
t_1
t_0
f_1
f_2
G_1
Gain

FIG. 11

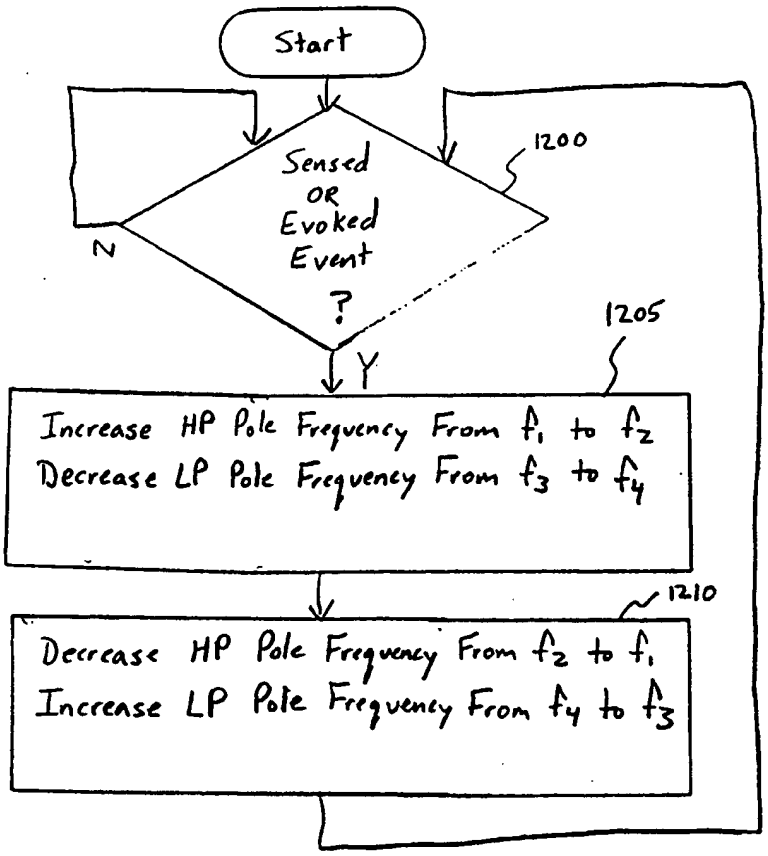
Start
Sensed OR Evoked Event ?
1200
N
Y
1205
Increase HP Pole Frequency From f_1 to f_2
Decrease LP Pole Frequency From f_3 to f_4
1210
Decrease HP Pole Frequency From f_2 to f_1
Increase LP Pole Frequency From f_4 to f_3

FIG. 12

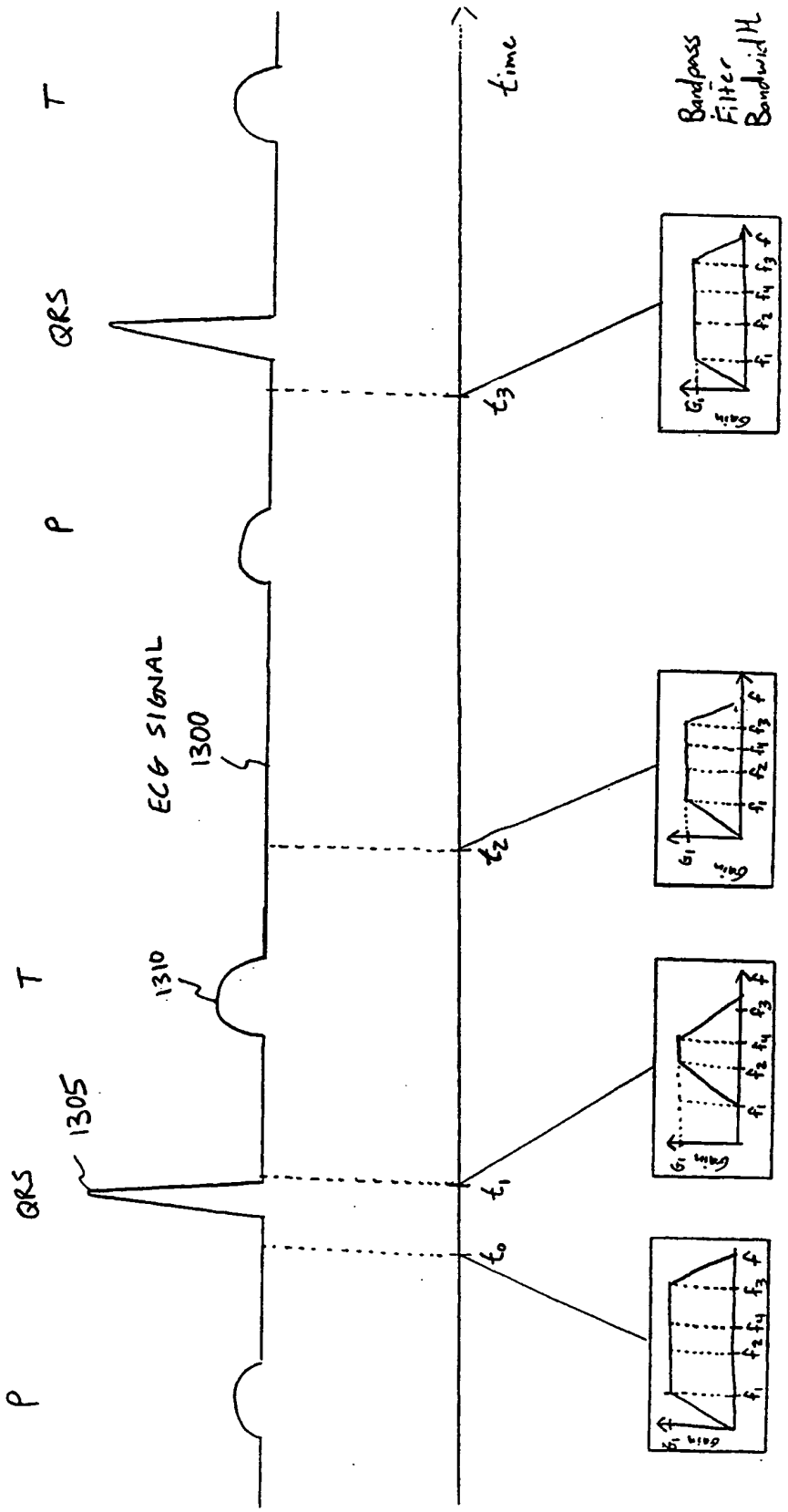
T
QRS
P
T
QRS
P
ECG SIGNAL
1300
1310
1305
time
Bandpass Filter Bandwidth
t_3
t_2
t_1
t_0
f_1 f_2 f_3 f_4 f
G_1

FIG. 13

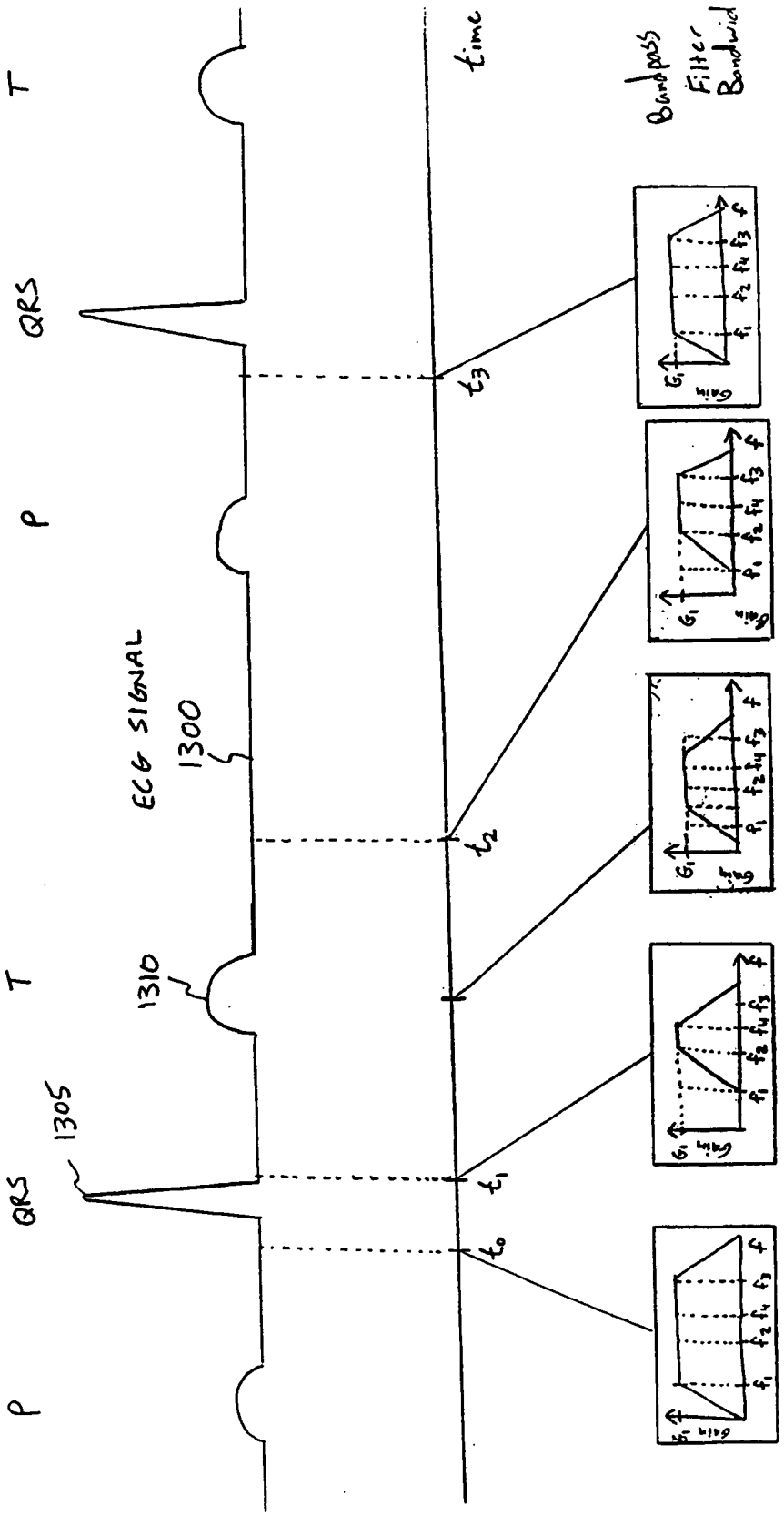
T
QRS
P
ECG SIGNAL
1300
T
1310
QRS
1305
P
time
Bandpass Filter Bandwidth
t_3
t_2
t_1
t_0

FIG. 14

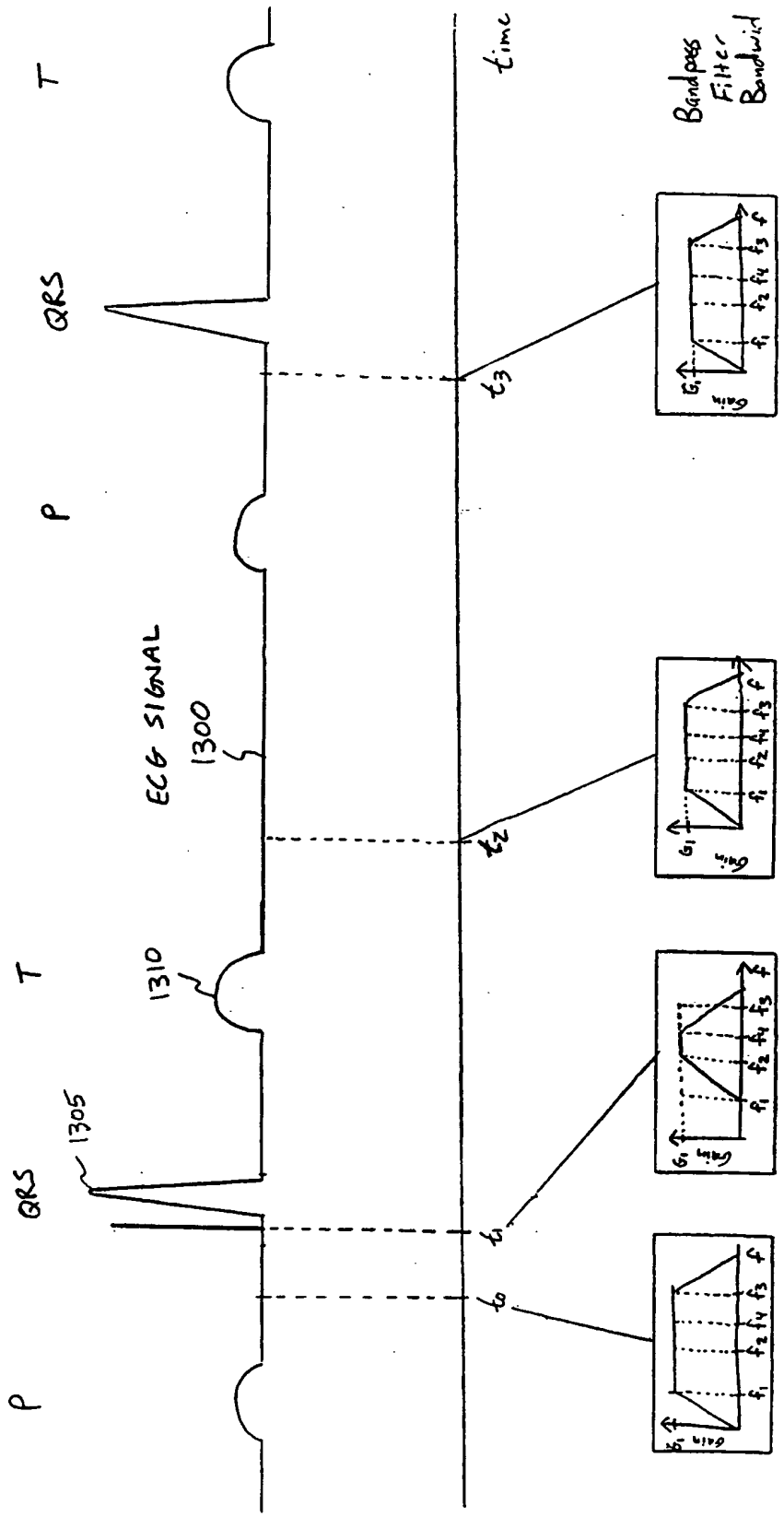
ECG SIGNAL
1300
1305
1310
QRS
T
P
QRS
T
P
time
Bandpass Filter Bandwid
t1
t2
t3
t4
Gain
G1
f1 f2 f3 f4 f

FIG. 15

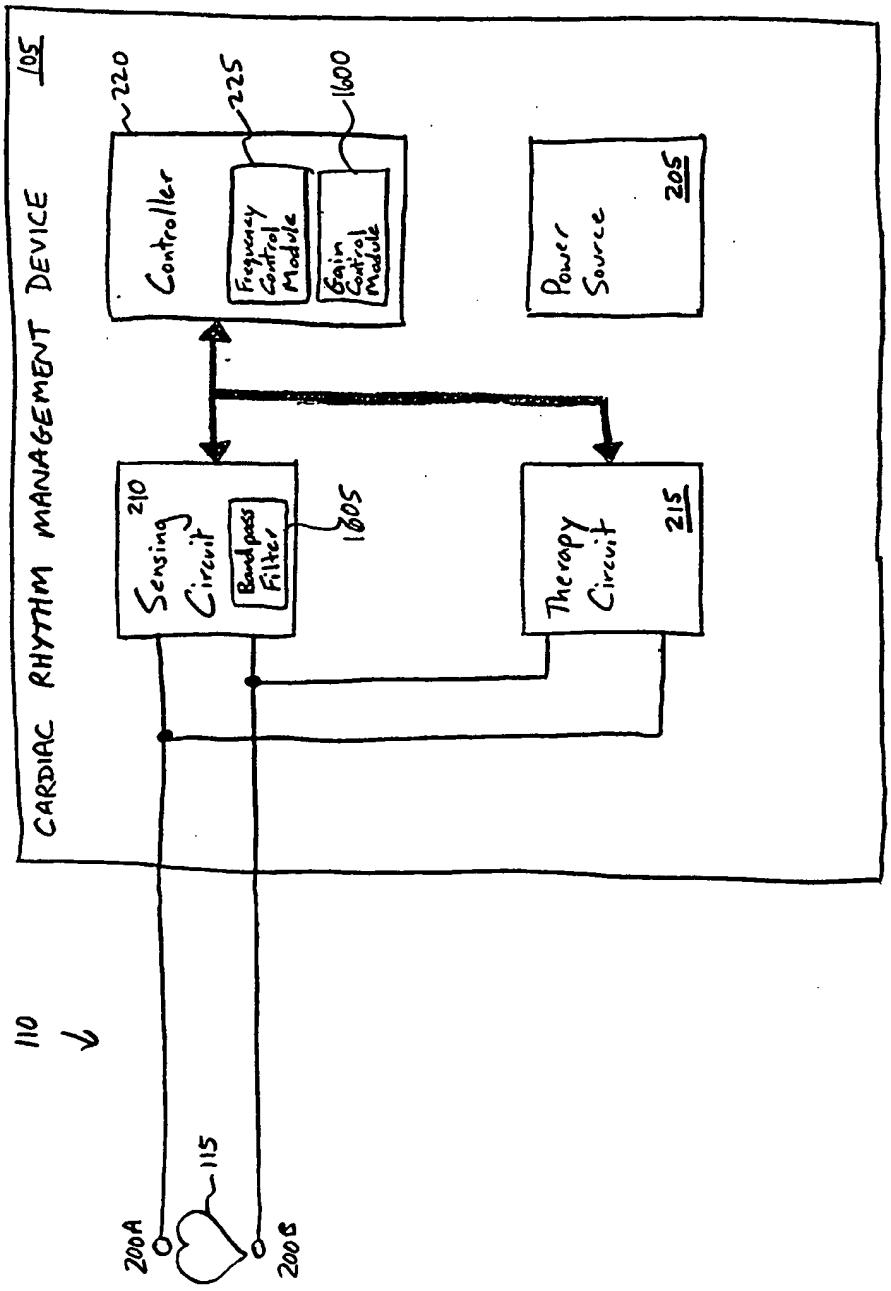
CARDIAC RHYTHM MANAGEMENT DEVICE
105
Controller
220
Frequency Control Module
225
Gain Control Module
1600
Power Source
205
Sensing Circuit
210
Bandpass Filter
1605
Therapy Circuit
215
110
115
200A
200B

FIG. 16

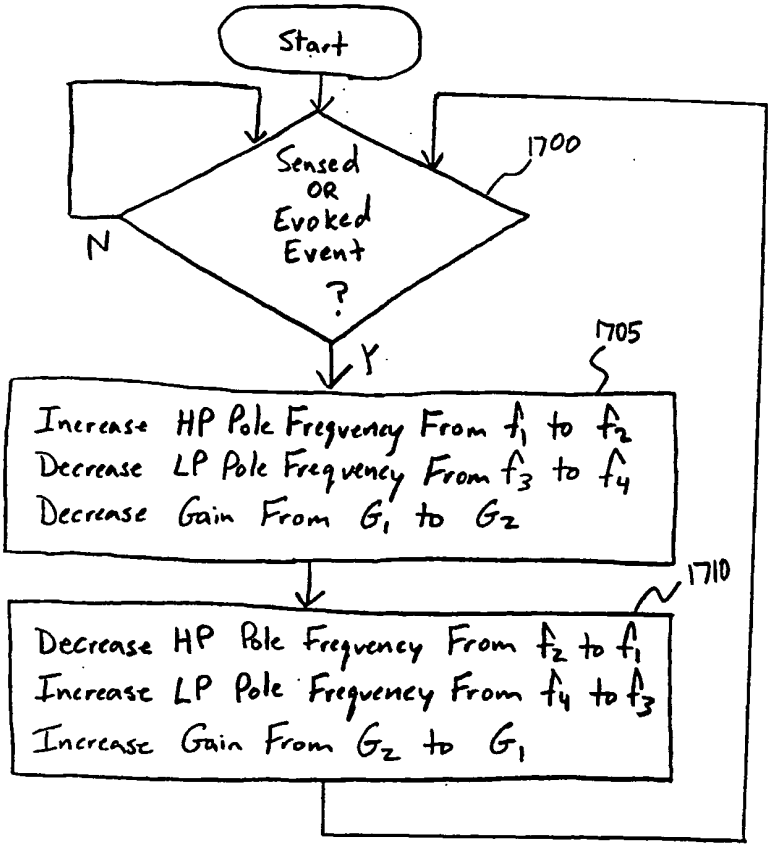
Start
Sensed OR Evoked Event ?
1700
N
Y
1705
Increase HP Pole Freqvency From f_1 to f_2
Decrease LP Pole Freqvency From f_3 to f_4
Decrease Gain From G_1 to G_2
1710
Decrease HP Pole Frequency From f_2 to f_1
Increase LP Pole Frequency From f_4 to f_3
Increase Gain From G_2 to G_1

FIG. 17

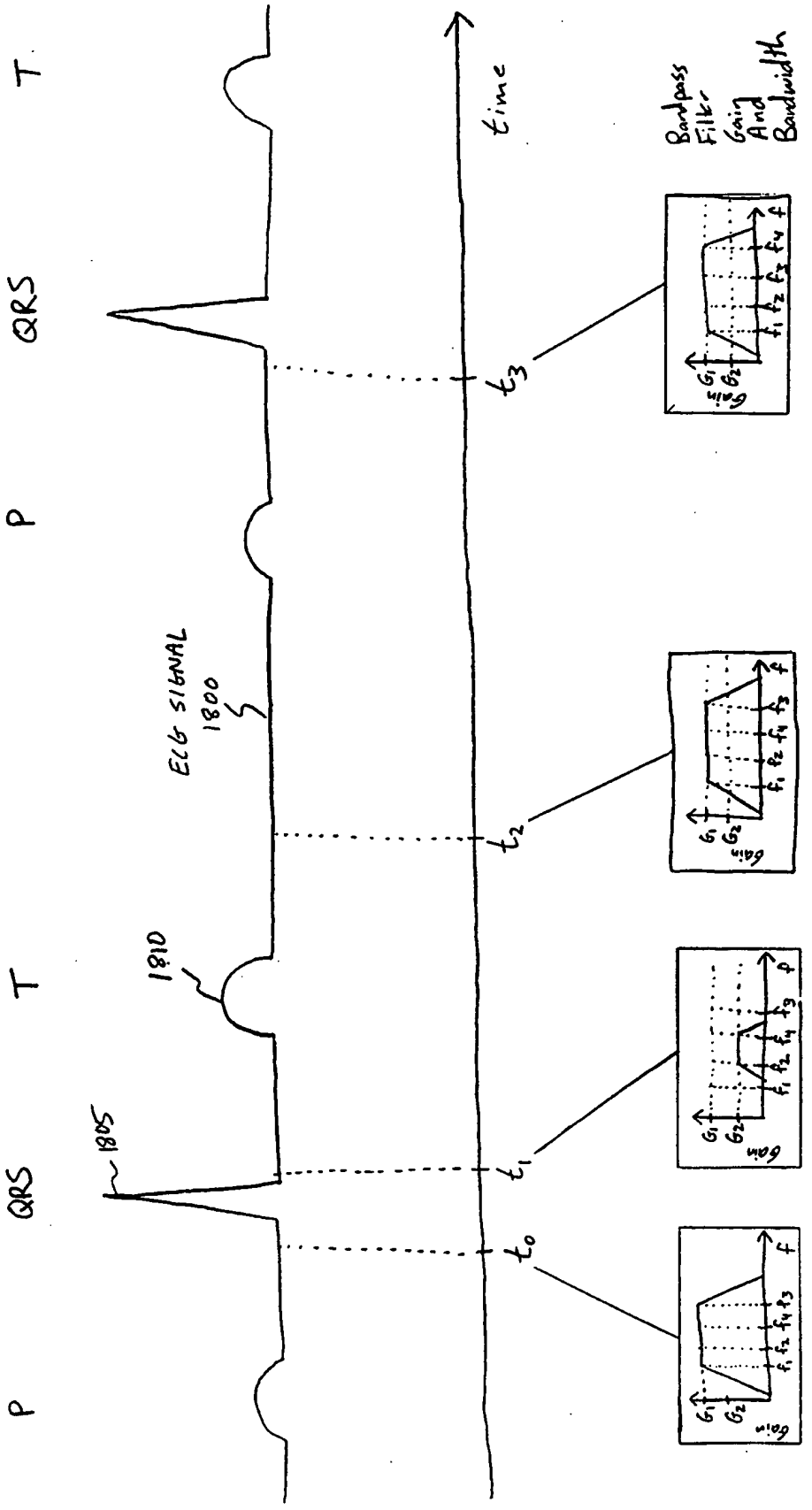
P
QRS
T
P
QRS
T
ECG SIGNAL
1800
1805
1810
time
t_0
t_1
t_2
t_3
Bandpass Filter Gain And Bandwidth
Gain
G_1
G_2
f_1 f_2 f_3 f_4 f

FIG. 18

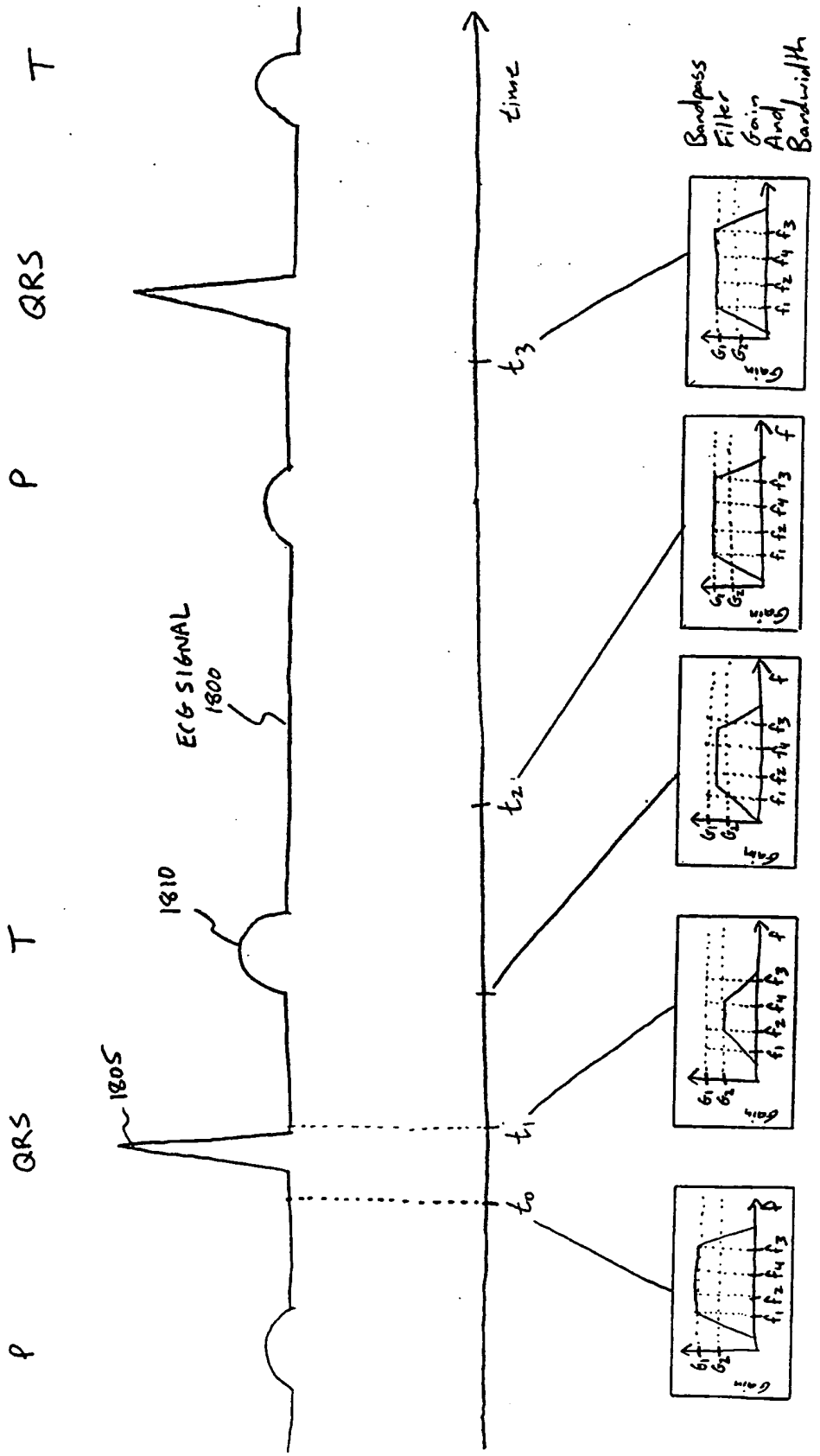
P
QRS
T
P
QRS
T
ECG SIGNAL
1800
1805
1810
time
t_0
t_1
t_2
t_3
Bandpass Filter Gain And Bandwidth
G_1
G_2
f_1 f_2 f_3 f_4
f

FIG. 19

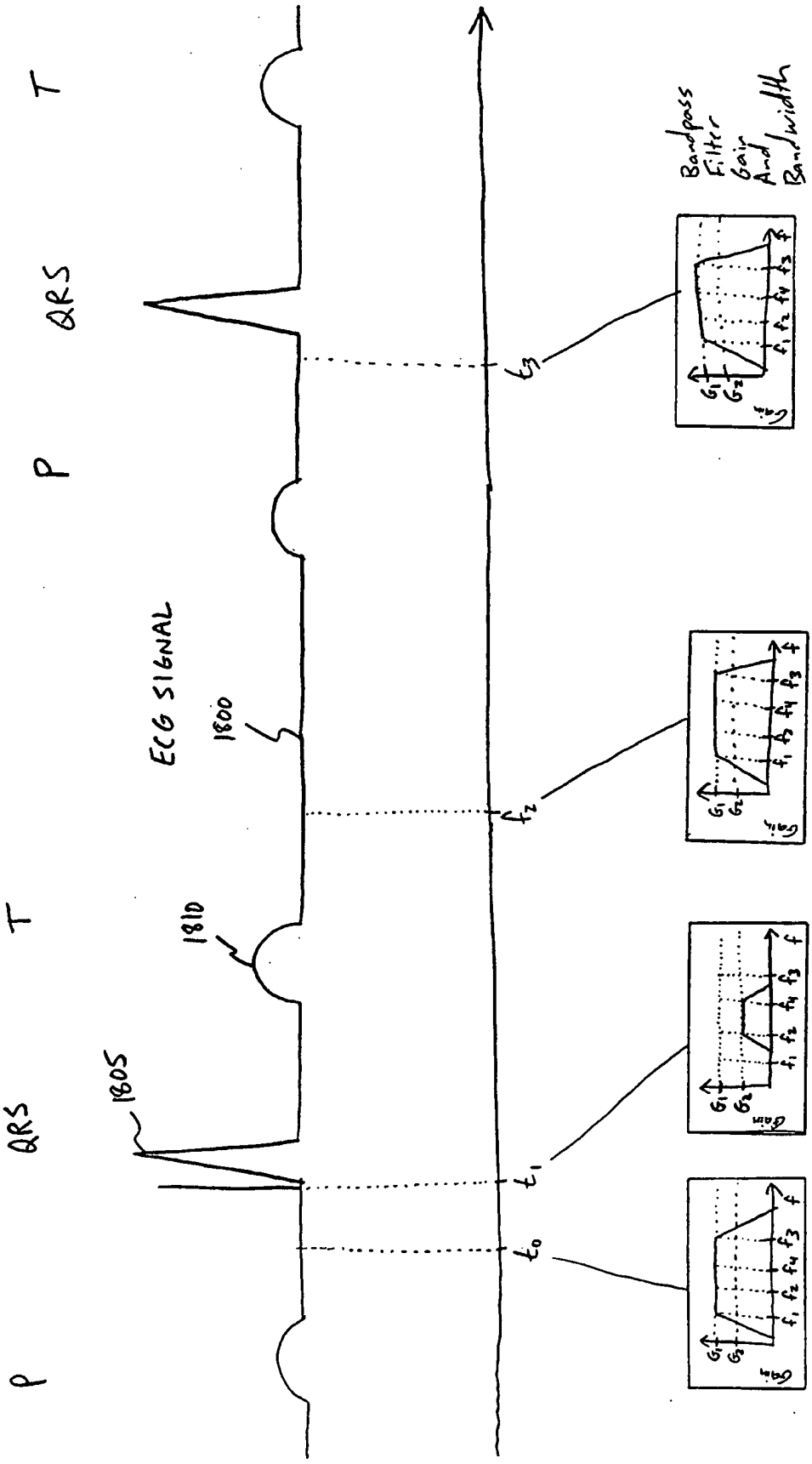
P
QRS
T
P
QRS
T
ECG SIGNAL
1800
1805
1810
t_0
t_1
t_2
t_3
Bandpass Filter Gain And Bandwidth
G_1
G_2
f_1 f_2 f_3 f_4 f

FIG. 20

INTERNATIONAL SEARCH REPORT

Im ational Application No
PCT/US 00/06090

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 A61N1/362

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 A61N A61B G06F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 357 969 A (HERLEIKSON EARL C) 25 October 1994 (1994-10-25)	1,24,25
A	column 1, line 56 -column 2, line 19	2-4,12, 13,15, 16,22
X	US 5 259 387 A (DEPINTO VICTOR M) 9 November 1993 (1993-11-09)	1,24,25
A	column 1, line 34-45	2,12,15, 18,22,28
A	EP 0 372 698 A (INTERMEDICS INC) 13 June 1990 (1990-06-13) column 3, line 39 -column 4, line 4	1,22,24
A	US 5 024 221 A (MORGAN WAYNE A) 18 June 1991 (1991-06-18) column 2, line 15-63	1,22,24

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
18 July 2000	25/07/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Grossmann, C.

1

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 00/06090

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5357969 A	25-10-1994	NONE	
US 5259387 A	09-11-1993	AU 2590692 A	05-04-1993
		WO 9305574 A	18-03-1993
EP 0372698 A	13-06-1990	US 5161529 A	10-11-1992
		CA 2004084 A,C	02-06-1990
		JP 2200274 A	08-08-1990
US 5024221 A	18-06-1991	NONE	